Implementing the Sustainable Energy (and Climate) Action Plans: Quasi-Steady State or Dynamic Modeling Approach

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Abstract

Actions contemplated in Sustainable Energy (and Climate) Action Plans (SEAPs), which municipalities adhering to the EU initiative called "The Covenant of Mayors" are required to prepare, regard many sectors, among which are buildings. To implement such plans, it is necessary to make use of methods for predicting energy use in buildings. Technicians involved in this tend to adopt easy-to-use simulation models because of the common mid-level expertise of the offices involved. However, such simplified methods could result in a less accurate evaluation of the energy demand of buildings. In this paper the suitability of the quasi-steady state and the dynamic approach, in the frame of these new urban energy planning tools, is assessed. Specifically, a comparison between the two methods reported in the EN ISO 52016-1 Standard (namely the quasi-steady state monthly method and the dynamic hourly method), used here as representative of the two cited classes of models, is drawn. Despite some limitations of the quasi-steady state model found in the analysis, the possibility to still use both modelling approaches to implement SEAPs is argued in the paper. Moreover, a tentative procedural scheme is proposed, which technicians working on SEAPs can usefully follow in order to choose the most appropriate modelling approach that can be used depending on the specific situation to address.

1. Introduction

In 2008 the European Commission launched an important initiative entitled the "Covenant of Mayors" (https://www.covenantofmayors.eu/en/), which intends to gather local and regional authorities voluntarily committed to achieving the greenhouse gas emissions reduction targets indicated in the EU "2030 climate and energy framework" (https://eur-lex.europa.eu/legal-content/EN). Signatories are required to develop and submit two plans, namely a Sustainable Energy Action Plan (SEAP) and a Sustainable Energy and Climate Action Plan (SECAP). Planned actions within both SEAPs and SECAPs should regard several sectors such as transport, energy, lighting, and buildings. The latter is certainly one of the most relevant sectors, due to the effect on both life of citizens and the energy consumption of a whole city (Giaccone et al., 2017).

In order to implement the cited plans, and particularly to define the above-cited energy efficiency actions for the building sector of a given territory, it becomes necessary to use methods aimed at the evaluation of the building energy performances. In this regard, technicians and experts have at their disposal two different categories of methods: quasi-steady state methods based on either a monthly or a seasonal balance, and detailed dynamic hourly methods.

Generally, technicians tend to exploit ease to use models (Peri and Rizzo, 2012) because of the commonly mid-level of expertise of the involved offices.

Consequently, quasi-steady state simulation models would seem the most attractive (instead of dynamic detailed models) for technicians, due to their intrinsic simplicity and for the fact that they require effortlessly available input data. Nonetheless, such simplified methods could result in a less accurate evaluation of the energy demand of buildings.

On the other hand, the high level of detail characterizing the dynamic modelling approach is not always necessary for the level of accurateness required by the type of analysis suited to a SEAP.

To clarify this aspect, it is worth noting that energy efficiency actions on buildings, planned within a SEAPs and SECAPs, may regard single buildings and/or building stocks. In both circumstances, the interventions may consist in the design, and/or in the energy rehabilitation (Marino et al., 2019). Specifically, the rehabilitation of a building stock may be conducted either on each single building of the stock (“detailed” rehabilitation of the stock) or may regard the stock in its entireness (“general” rehabilitation). Therefore, as depicted in Fig. 1, if the intervention consists in the design or in a “general” rehabilitation of a building stock, then using a dynamic modelling approach, which requires considerable amount of input data and shows a greater complexity of use, might turn out unnecessary. Indeed, in this case, buildings characterized by “standardized” performances (“virtual” sample buildings that can be assumed as representative of the considered stock) will have to be modelled and to do this, a detailed definition of the building envelopes, HVAC, orientations, etc. is not needed. Therefore, in such circumstances, despite its limits, choosing the quasi-static method would be preferable.

Conversely, if the action consists in designing or rehabilitating single buildings, the quasi-steady state approach would not be compatible with the accuracy required for the analysis. In this case, a model for predicting the energy use that is able to reproduce the specific building envelope, HVAC system, usage profile, and that is able to capture the dynamic behaviour of the given building should be used.

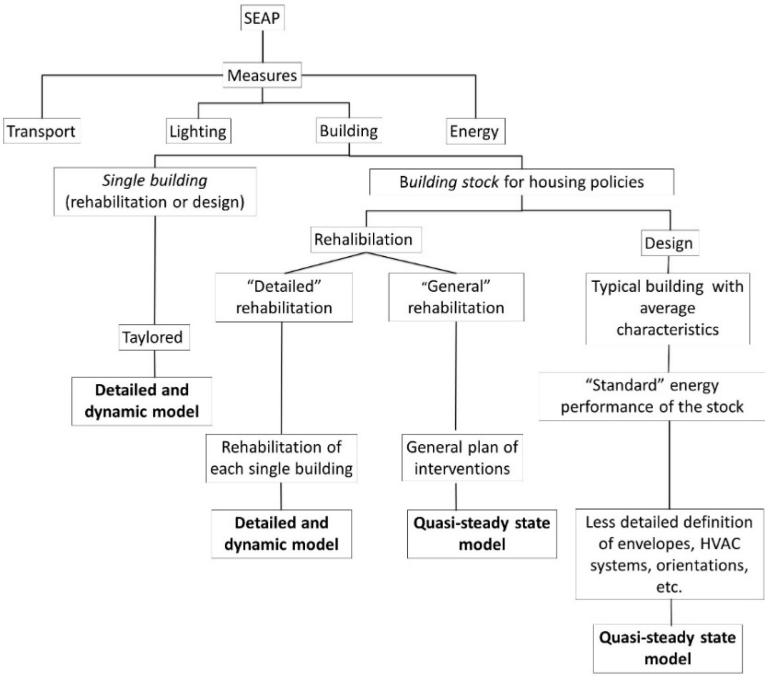

Fig. 1 – Tentative approach for the selection of the most suitable type of energy simulation model

Starting from these considerations, this paper further discusses the practicability of the quasi-steady state and dynamic modelling approaches, as tools that can be used within the decision-making process leading to selection and implementation of energy efficiency measures in various climate configurations by urban planners.

To accomplish this task, as representative of both cited different approaches, two simulation models have been selected, i.e. the quasi-steady state monthly method and the dynamic hourly method, both devised by the recently issued EN ISO 52016-1 standard. Specifically, for a plain sample building, located in sites characterized by different weather configurations (Athens, Messina, and Rome), the results obtained using these two methods were compared to the outcome yielded by the well-known building dynamic simulation code, that is Energy Plus (used as a reference).

Based on the analysis performed, some further criticisms of these two modelling approaches have arisen with reference to their use in the frame of the above cited energy planning tools for sustainable and resilient cities.

2. Materials and Methods

2.1 The Analysis Approach

To fulfil the aim of this work, we have selected two simulation models, used here as representative of the two previously cited classes of approaches thanks to their large popularity among technicians and researchers. These are the monthly and the hourly models devised by the recently issued EN ISO 52016-1 standard (CEN, 2017) that replaces the EN ISO 13790 (CEN, 2008); the standard constitutes a reference to the energy performance certification of buildings at national or regional levels. The models were implemented in Excel™ spreadsheet and Visual Basic™ functions were also used.

A plain sample building was considered and its monthly energy consumption was calculated using both the quasi-steady state monthly model and the hourly dynamic model.

Clearly, to properly carry out comparisons among different calculation procedures, univocal climate data are needed; therefore, a database which is suitable for all the procedures must be selected. After a careful analysis, the database of the Energy Plus simulation software (U.S. Department of Energy, 2017) was identified as complete and suited to this purpose. Data concerning outside temperature and solar radiation were obtained.

The results gained through the two EN ISO 52016-1 standard methods were compared with the outcomes of dynamic simulations performed by means of the Energy Plus code (Crawley et al., 2001). The analysis was repeated in three different cities, namely Messina, Rome and Athens, considered here as representative of weather conditions typical of the Mediterranean climate.

In this context, proper attention was paid to input data such as envelope data, building use data and climatic data, because their uncertainties may produce an important variation in the assessed energy performance and label (Corrado and Mechri, 2009). In order to reduce this type of uncertainty, univocal databases were used in spite of the fact that the three considered calculation methods often require different typologies of input data (e.g. monthly or hourly average air temperatures.

The building module and the climate characteristics of the selected sites are described in the following sections.

2.2 Building Module Characteristics

With a view to executing the described comparison, the building module reported in Fig. 2 was studied. Its dimensions are 5.00 m x 5.00 m x 2.70 m. The vertical structures and the roof are non-adiabatic and facing outdoor, so that their outside boundary condition consists of the outdoor environment, whereas the floor, which is also non-adiabatic, has soil as the outside boundary condition. On the South wall, a glazed surface is installed and its dimensions are 1.20 m x 1.40 m (Fig. 2).

It is worth underlining that the shape described would not be considered as representative of any building practice. It has been selected in order to verify the compliance of simulation codes with the purposes of a SEAP (or SECAP) application. In other words, the analysis aims at providing information able to lead administrators in the choice of steady-state or dynamic approaches in their building energy evaluations. Because of this, a generic shape has been adopted for the building module. The South-facing window allows the solar radiation to be taken into account. However, since among the selected sites warm climates are involved, the window area was reduced in order to avoid the overheating phenomena that could occur in warmer climates.

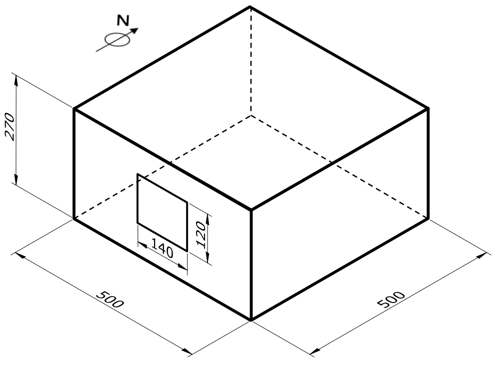

Fig. 2 – Description of the building module used for simulations

The thermal transmittance values of the envelope structures are: 1.70 W/m^{2}K for the glazed surface, 0.85 W/m^{2}K for external walls, 0.80 W/m^{2}K for the floor, 0.36 W/m^{2}K for the roof. Heat capacity per area is: 432 kJ/m^{2}K for walls, 402 W/m^{2}K for the floor and 501 W/m^{2}K for the roof. These values have been adopted here as representative of the more recent (constructed after 1990) Italian building stock (http://www.building-typology.eu; Corgnati et al., 2013) with improvements due to renovations typical of the last few years (Bertini et al., 2018).

In more detail, in the case of glazed surfaces, whose values are traditionally higher than 3 W/m^{2}K, we decided to push values towards those typical of an advanced refurbishment since these components are the ones that can more easily be modified compared to the opaque parts of the envelope and therefore are usually subject to the first energy refurbishment actions, especially considering the technical improvement they are currently undergoing (Piccolo et al., 2018). On the other hand, the substitution of these envelope components also induces acoustical benefits to the building occupants: this is another reason why building owners often tend to modify them. These values were also preliminarily assumed valid for Athens.

As regards the typology, the edifice is an office building, the thermostat control strategy was assumed as continuous with a constant temperature set-point of 20°C. The infiltration rate was set to 0.5 air change/h continuously (24 hours per day for the full year). No ventilation system is present (CEN, 2017). The internal heat gains were evaluated with a constant value of 6 W/m^2 (UNI, 2014). No shading devices are present and the effect of obstructions was not taken into account.

2.3 Climate Characteristics of the Selected Sites

As stated earlier, the energy simulations were carried out considering the building module located in three different cities in the Mediterranean area: Athens (37° 54′ North Latitude, 23°43' Est Longitude; 1112 °C HDD, 2966 °C CDD); Messina (38°12′ North Latitude, 15°33' Est Longitude; 758 °C HDD, 3261 °C CDD); Rome (41°47′ North Latitude, 12°13' Est Longitude; 1444°C HDD, 2333 °C CDD),

With regard to the ASHRAE climatic classification system, based on the heating and cooling degree days (ASHRAE, 2010), the selected cities are located in two different climatic zones, that is: warm (Messina and Rome) and mixed (Athens).

3. Results

For the case study described in the previous section, the heating and cooling monthly energy demand were calculated. These results were further exploited to assess the energy needs on a seasonal basis.

For the sake of simplicity, and without prejudice for the generality, the simulations were conducted with a constant set-point of 20°C for the internal air temperature for every month of the year: this avoids the problem of the preliminary identification of different heating and cooling periods for each considered location.

For each of the three selected cities, the energy needs for heating and cooling, were calculated for the 12 months of the year, thereby obtaining 72 output data for each of the adopted calculation methods (steady state and dynamic).

Aggregated results are shown in Fig. 3, where the monthly values of energy demand obtained by means of both the monthly and hourly methods are reported versus the Energy Plus output (EP) which was adopted as a reference.

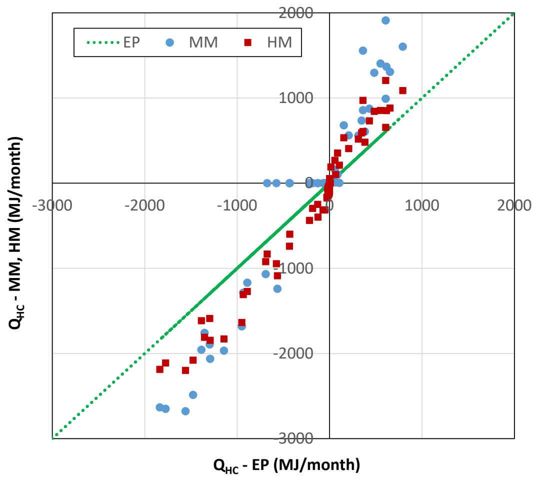

Fig. 3 – Comparison of the monthly energy needs for heating (positive values) and cooling (negative values), obtained with both the monthly (MM) and the hourly (HM) methods with those obtained with EnergyPlus (EP) for all the considered cities

The diagram of Fig. 3 shows that, assuming Energy Plus output as a reference, the monthly method (MM) significantly (R^2 =0.925 for MM and R^2 = 0.966 for the HM) overestimates the monthly demand, during both heating and cooling periods. Furthermore, the higher the value of the energy demand, the larger the difference between the two methods. This phenomenon is barely evident for the results of the hourly method (HM), its outcome being very close to the Energy Plus output (EP).

As regards the seasonal energy demand, Fig. 4 reports the yearly cooling and heating energy needs for each of the analysed cities.

It can be noted that even on an annual basis, in comparison to Energy Plus, the monthly method overestimates the heating energy needs more than the hourly one. This behaviour does not regard the cooling needs; indeed, in this case, the results of the monthly method are lower than the values calculated by means of the hourly method. The reasons behind this behaviour are more easily inferable from Fig. 5, which reports, for the site of Rome, the monthly needs for heating and cooling at each site. Specifically, graphs show six different profiles: three in the upper part of the diagram pertinent to MM, HM, and EP, extended over 12 months and referring to space heating (clearly, in the months when heating is not required, the methods provide a value of zero energy), and three in the lower part of the diagram pertinent to MM, HM, and EP, extended over 12 months and referring to cooling (clearly, in the months when cooling is not required, the methods provide a value of zero energy).

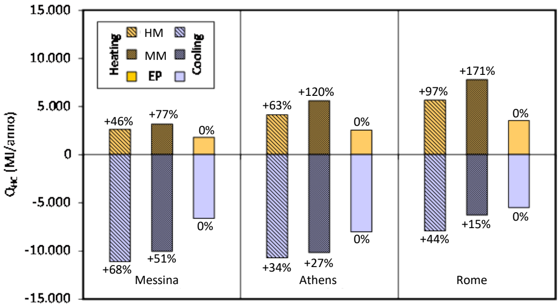

Fig. 4 – Seasonal energy demand for heating and cooling purposes: monthly method (MM), hourly method (HM), EnergyPlus (EP)

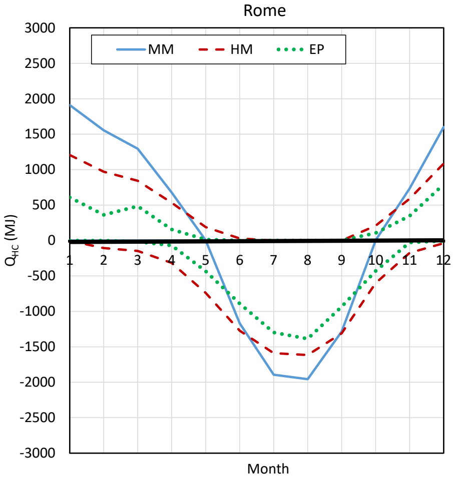

Fig. 5 – Monthly needs for heating (positive values) and cooling (negative values) purposes

It is shown that although the monthly method yields generally the greatest values of energy demand during the hottest months, it returns the smallest values (equal to zero) during spring/autumn.

The combined effects of these two occurrences make the yearly cooling demand assessed through the monthly method smaller than the one calculated by means of the hourly method. This occurs because of the intrinsic structure of the monthly method that, using the monthly average values of the outdoor air temperature as input data, does not allow simultaneous calculation of possible occurrences of heating and cooling for the same month, which is the case in spring/fall periods. In other words, at least one of the two terms is zero for the intrinsic structure of the monthly method.

By contrast, both the hourly method and the Energy Plus code use hourly values of the outdoor air temperature as input data and, hence, they allow the contemporary assessment of both heating and cooling daily loads when they occur

To sum up, as can be observed from Fig. 4, the hourly method always overestimates the cooling energy needs compared to the base case (and more than the monthly method, which overestimates them as well) In terms of the space heating, the hourly method overestimates the energy needs with respect to the base case but less than the monthly method.

4. Discussion

As earlier stated, the purpose of the proposed analysis is not the assessment of the accuracy and reliability of the quasi-steady state and dynamic methods in predicting the building energy performances, but rather the evaluation of their suitability in sight of their utilization within the process leading to selection and implementation of energy efficiency measures in Mediterranean climate configurations by urban planners and building technicians who work on SEAPs. In other words, the aim of the analysis is to possibly identify the most appropriate model that can be used in each of the situations depicted in Fig. 1.

Results shown in the previous section outline the different behaviour of the two modelling approaches depending on the type of assessment, whether monthly or seasonal. The results show that on one hand, the quasi-steady state approach permits an easy assessment of the seasonal energy demand of buildings both for its intrinsic simplicity and for the fact that it requires effortlessly available input data (features that render this approach particularly attractive for technicians). On the other hand, it is affected by some relevant limitations as it significantly overestimates the monthly demand, during both heating and cooling periods, and concerning the seasonal demand, it overestimates the heating energy needs more than HM with respect to Energy Plus.

Results of HM and Energy Plus, both of which are based on transient regime thermal balances, were instead found comparable, and compliant with the climate time variability characterizing the sites, allowing more reliable analysis when coexistence of heating and cooling loads is highly possible.

Some considerations can therefore be provided concerning the level of suitability of the quasi-steady state method (MM) and the hourly dynamic method (HM) in the frame of SEAPs (or SECAPs).

Among the main features of the MM there is the simplicity of the model structure and the requirement of easily available input data. Both these two features render the MM suitable for the development of a SEAP, because the first one matches the mid-level expertise of the committed offices, while the second one matches a common circumstance of the committed offices, i.e. the set of data (definition of envelope, HVAC features, etc.) needed for detailed analyses is generally not completely available.

Another characteristic of the MM is that no greatly detailed building/HVAC modelling is required. Because of this, the suitability of the MM approach depends on the required level of accuracy of the analysis to be performed, whether high, low, etc. Therefore, in the context of SEAPs, the MM turns out to be more appropriate in the case of the design and “general rehabilitation” of a building stock (Fig. 1). In this case, buildings characterized by “standardized” performances (“virtual” sample buildings that can be assumed as representative of the considered stock) will need to be modelled and to do this, a detailed definition of the building envelopes, HVAC, etc. is not required.

Results of our analysis also signal that when using the MM, a possible overrating of the monthly energy demand (both in heating and cooling seasons), and the annual heating energy demand could occur. Such a characteristic renders the MM suitable for the development of a SEAP although some misinterpretations could occur. Consequently, the MM turns out to be more appropriate for reliable estimations of the cooling energy demand and for rough estimations of monthly energy savings deriving from a planned set of measures, for instance, for the “general rehabilitation” of a building stock, and in the case of rough estimations of yearly energy savings for space heating.

Furthermore, outcomes of our analysis indicate that a possible miscalculation of the energy demand in mild climate or mild months (spring/fall), when both heating and cooling needs might coexist, could occur due to its dual intrinsic structure. This feature makes the MM suitable for the development of a SEAP even if some concerns arise. Because of this, the MM turns out to be more appropriate in the case that the analysis regards the energy demand for well-characterized seasons (heating and cooling) which are clearly separated. If shorter periods need to be investigated (for instance because the edifices are used for a limited period during the whole year), more detailed methods should be exploited, instead.

Among the main features of the MM there is the complexity of the model structure and the requirement of a considerable amount of not easily available input data. Because of these factors, the HM is suitable for the development of a SEAP but only in those cases when a detailed analysis is required and when the amount and type of needed data is at the disposal of the offices responsible for the action planning.

Another characteristic of the HM is that it requires a high level of detail due to, for instance, the consideration of the hourly variation of the weather conditions as input data. Because of this, the suitability of the HM depends on the required level of accuracy of the analysis to be performed (high, low, etc.). Therefore, in the context of SEAPs, the HM turns out to be more appropriate in the case of the design or the rehabilitation of single buildings, and in the case of a "detailed rehabilitation" of a given building stock (Fig. 1).

Results of the analysis also signal that a possible overestimation of the annual cooling demand could occur. Such a characteristic renders the HM suitable for the development of a SEAP although some misinterpretations could occur. Consequently, the HM turns out to be more appropriate for accurate estimations of heating and in the case of rough estimations of cooling energy saving deriving from planned set of measures, for instance, on a single building for its rehabilitation.

Furthermore, outcomes of the analysis signal that coexistence of both heating and cooling needs is suitably taken into account by the HM. This feature renders the HM suitable for the development of a SEAP because it makes it possible to have a more realistic image of the energy consumption of the single building or of the given building stock. Because of this feature, this method turns out to be more appropriate in the case of accurate estimations of the energy saving even in the mild months.

5. Conclusions

The purpose of the proposed analysis is not the assessment of the accuracy and reliability of the quasi steady-state and dynamic methods in predicting the building energy performances, but rather the evaluation of their suitability in sight of their utilization within the process leading to selection and implementation of energy efficiency measures by urban planners and building technicians who work on SEAPs, particularly in Mediterranean climate configurations. In other words, the aim of the analysis is to possibly identify the most appropriate model - whether it exists – which can be used in each of the situations depicted in Fig. 1.

The results have outlined the different behaviour of the two modelling approaches, whether monthly or hourly. These results show that on one hand, the quasi-steady state (monthly) approach permits an easy assessment of the seasonal energy demand of buildings both for its intrinsic simplicity and for the fact that it requires effortlessly available input data (features that render this approach particularly attractive for technicians). On the other hand, it is affected by some relevant limitations, that is: it is not able to properly evaluate the monthly demand during spring/fall periods when heating and cooling needs may coexist and overestimates the heating energy needs more than the hourly method with respect to Energy Plus; however, it performs with greater accordance to Energy Plus as far as the yearly cooling demand is concerned.

Results of the hourly method and Energy Plus, both of which are based on transient regime thermal balances, were instead found comparable on a monthly basis and compliant with the climate time variability characterizing the sites.

Based on these considerations and criticisms, further analyses are needed particularly referring to other climatic situations of different sites. Additionally, the present analysis should be properly extended to other building typologies and thermos-physical envelope characteristics. Meanwhile, technicians working on SEAPs can usefully follow the tentative procedural scheme presented in the Introduction and discussed in Section 4, in order to choose the most appropriate modelling approach suited to the specific situation to be addressed in SEAP design. Until further research findings become available, such a scheme as presented in this paper, represents a precautionary approach that can be followed, being based on reasonable considerations concerning the compliance between the kind of method adopted for the simulation and the level of the results required.

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